PO.ID 177

# Using backward nacelle LiDARs in wake characterization for wind farm optimization

J.W. Wagenaar[1], K. Boorsma[1], E. Bot[1], S. Davoust[2] and B. Svardal[3]
1. ECN, Unit Wind Energy, P.O. Box 1, NL 1755 ZG Petten, Netherlands
2. Avent Lidar Technology, 14-16 rue Jean Rostand, 91400 Orsay, France
3. Christian Michelsen Research AS, P.O. Box 6031, 5892 Bergen, Norway

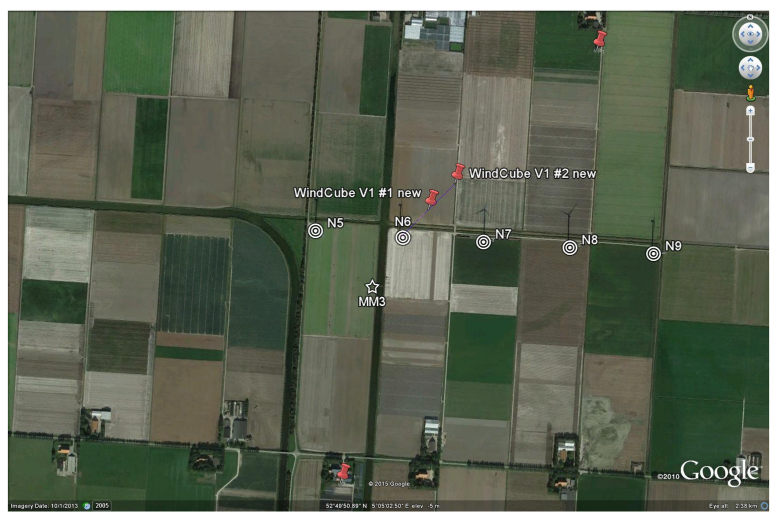
ECN

## 1. Introduction

In large offshore wind farms wakes play a very important role in terms of reduced yield and increased fatigue loading. Nacelle LiDARs, being relatively easy to install, offer wind farm operators the opportunity of better insight in the operation of their wind farms and to provide a pathway for performance improvements. Therefore, in this work two nacelle LiDARs are placed on a full scale wind turbine in a backward mode with the aim to quantify wakes and wake evolution. In order to do so the LiDARs are validated against an IEC compliant meteorological mast.

A Wind Iris two beam nacelle LiDAR and a Zephir 300 prototype nacelle LiDAR are placed in a backward mode on a 2.5 MW ECN research turbine on flat terrain. Here, the Wind Iris is oriented such that one beam is aligned with the nacelle. A fully instrumented IEC compliant meteorological mast is nearby and for some time two WindCube V1 ground based LiDARs were present.

## 2. Experimental set-up




*Layout of the test site with turbines, mast and LiDARs indicated.*

**ECN Test Site**
- Flat terrain
- 5 research turbines
- West to East
- 2nd from West

**IEC mast (MM3):**
- Cups, vanes and sonics at 80m
- 2.5D from turbine
- South-West

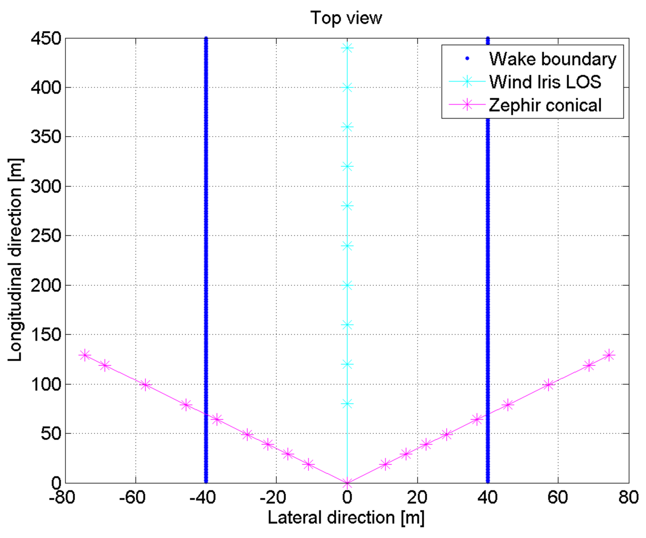
**Turbine (N6):**
- Nordex
- 2.5MW
- H=D=80m

**Wind Iris:**
- Single beam
- Along nacelle
- 1D to 5.5D, 10 steps

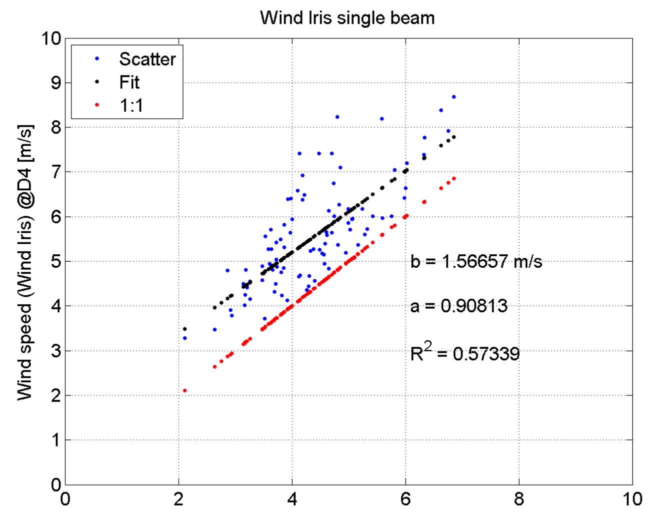
**WindCube V1's:**
- 1.8D & 3.5D from turbine
- North-East

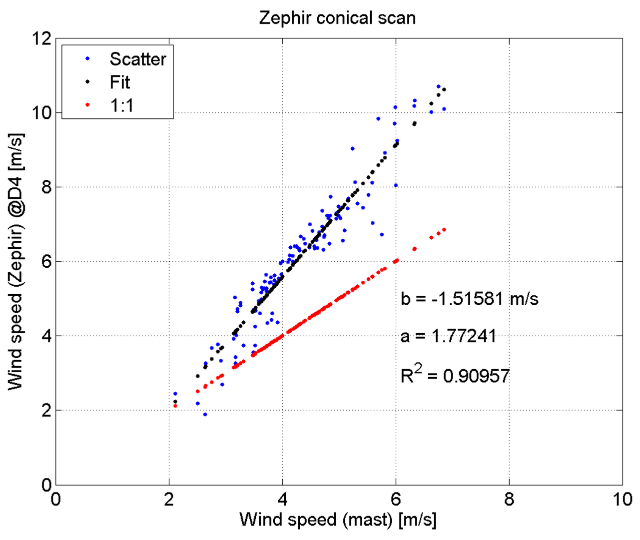
**Zephir:**
- Conical scan
- 0.24D to 1.6D, 9 steps
- Inside and outside wake

*Schematic overview of wake and scan patterns*




## 3. Validation




The nacelle LiDAR wind speed measurements are validated against the mast for strictly North-East winds. The Wind Iris measurement distance of 200m is used and for the Zephir the distance of 49m. The latter is the largest distance still inside the wake.

**Results Wind Iris**
- Overestimation in considered range
- Linear fit parameter reasonable (a=0.91)
- Poor fit ($R^2$=0.57)

➢ LiDAR settings okay?
➢ Wake dynamics
➢ Qualitative use

**Results Zephir**
- Overestimation in considered range
- Linear fit parameter poor (a=1.77)
- Reasonable fit ($R^2$=0.91)

➢ LiDAR prototype
➢ Measurement distance
➢ Wake dynamics
➢ Qualitative use

## Acknowledgements

Work presented here was carried out in the framework of the ‘Lawine’ project with subsidy from the Dutch funding scheme TKI ‘Wind op Zee’. The following people are acknowledged for their contributions: Gerben Bergman and Frank Kaandorp (ECN), Valerie-Marie Kumer (NORCOWE, University of Bergen).

## 4. Wake Characterization

Data are selected for winds from the South-West to measure in a single wake. The Zephir measures the near wake (0.24D to 0.8D) and the Wind Iris the further wake (1D to 5.5D). The remaining Zephir measurements are at the border of or outside the wake. The mast measurements determine the inflow conditions.

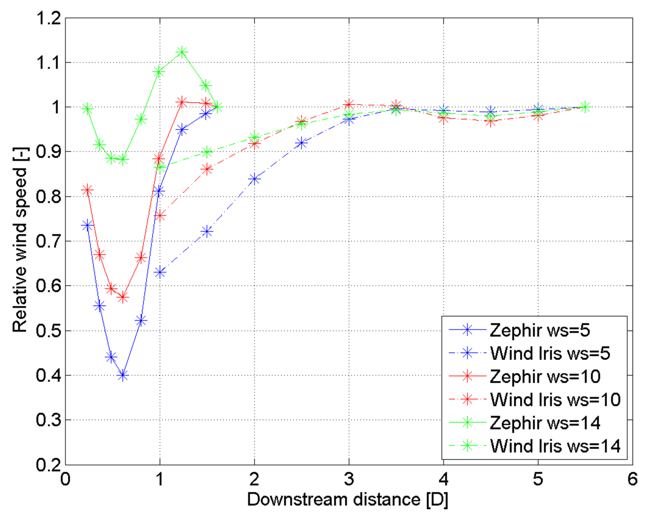



*Figure 1*

| Situation | Filtering | Results |
|---|---|---|
| Nacelle LiDARs relative wind speed. Normalized at largest distance (**Figure 1**) | Inflow wind speed at mast<br>- 3<wind speed<5. Just above cut-in<br>- 9<wind speed<11. Optimal pitch<br>- 13<wind speed<15. Around rated; pitching | ▪ General wake profile: dip in the near wake and recovery further downstream<br>▪ Profile from Zephir and Wind Iris ‘connect’ reasonably<br>▪ Zephir measurements from around 0.8D on are around the wake border and outside<br>▪ For low wind speed the wake deficit is largest<br>▪ Flattened profile at 14m/s due to pitching<br>▪ Unclear dip at 4.5D. Influence of other wakes? |
| Nacelle LiDARs standard deviation wind speed (**Figure 2**) | Inflow wind speed at mast<br>- 0.05<TI<0.07<br>- 0.09<TI<0.11<br>- 0.13<TI<0.15 | ▪ The standard deviation in the wake is higher for high inflow turbulence intensity<br>▪ The Zephir measurements at 0.8D and 1D show a clear increase in standard deviation. The measurements are just before and at the wake border<br>▪ Low variation standard deviation from 1D to 5.5D |
| Nacelle LiDARs wind speed; 8m/s inflow. Zephir data scaled such that wind speed at 1.6D is 8m/s (**Figure 3**) | 7<Inflow wind speed<9<br>- Low inflow TI (TI<0.08)<br>- High inflow TI (TI>0.12) | ▪ Higher wind speed deficit for low inflow turbulence intensity<br>▪ Faster wake recovery for high inflow turbulence intensity |

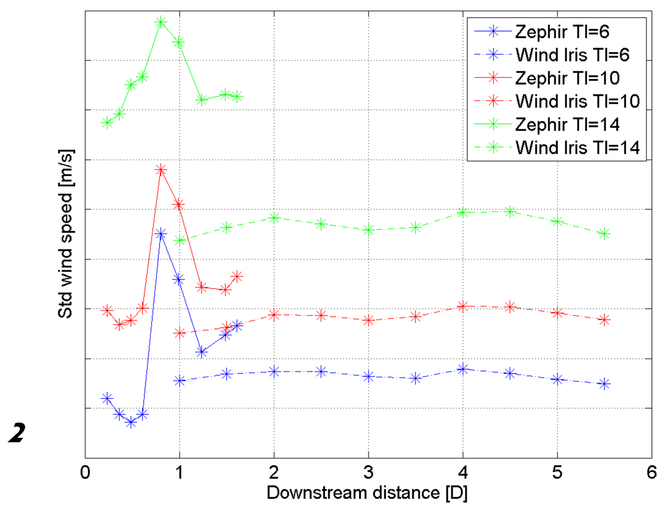



*Figure 2*

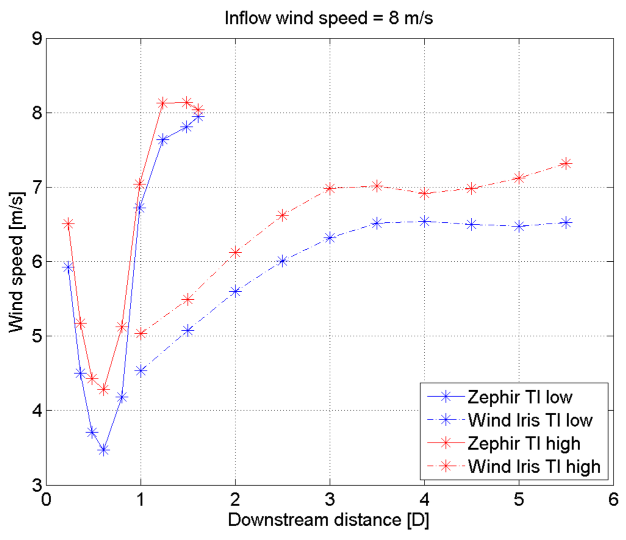
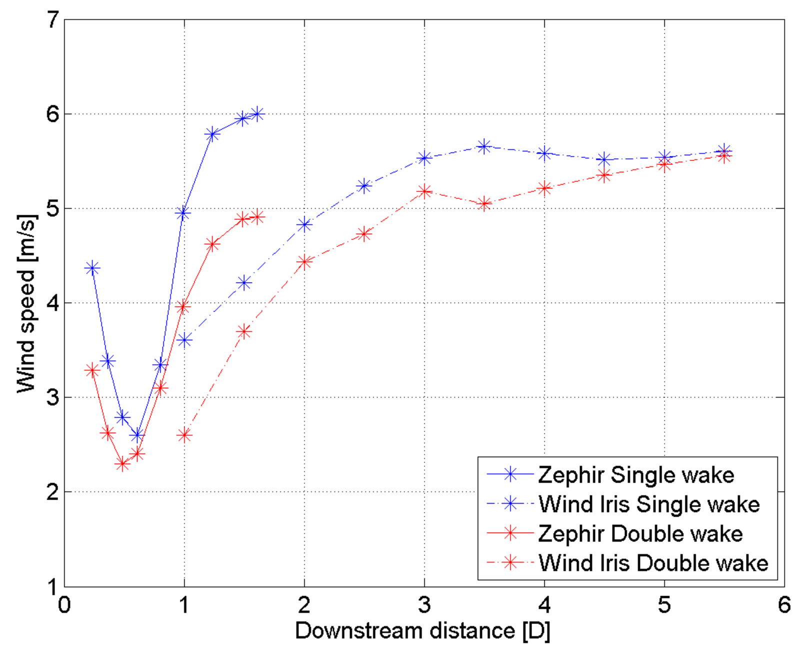



*Figure 3*

A **single wake** (turbine faces undisturbed wind) situation is compared to a **double wake** (turbine faces a wake) situation. In case of the single wake data are again considered from South-West. For the double wake data are strictly selected from the West with a wind direction window of 5 degrees. Both data sets have an average inflow wind speed of 6m/s and a turbulence intensity of about 10%. Both Zephir profiles are scaled in the same way such that the Zephir measurement of the single wake (blue) at 1.6D is 6m/s (mean infow).

**Results**
- Profiles from both LiDAR ‘connect’ reasonably
- Wind speed deficit higher in double wake
- Clear dip in double wake profile (red) at 3.5D. Wake faces third turbine
- Dip in double wake profile at 3.5D less deep than expected.




## 5. Conclusions

➢ The nacelle LiDARs do not correlate well with the mast. This is due to the operation of the LiDARs (Zephir: prototype, conical scan. Wind Iris: single beam) in combination with the highly dynamic nature of the wake. A qualitative approach works well.
➢ The nacelle LiDARs complement each other (near wake vs further wake) and the profiles ‘connect’ reasonably. Together they form a representative wake profile. The Zephir LiDAR clearly indicates the wake border.
➢ Different inflow conditions (wind speed, turbulence, wake) have a clear and expected influence on the wake profiles.